ERP Correlates of Cyclic Computations: Anaphora in Native and L2 French

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1. Introduction

In psycholinguistic research, some have argued that second language (L2) sentence processing engages domain-specific computations of syntactic structure, as in a first language (L1), under reduced capacity (Dekydtspotter, Schwartz, & Sprouse, 2006; Dekydtspotter & Miller, 2013; Hopp, 2016a, 2016b; Miller, 2015). Others argue that typical grammatical processing is thwarted (Clahsen & Felser, 2006a, b) due to L2 representations that are peripheral to Universal Grammar (UG) (Bley-Vroman, 1989; 2009; Clahsen & Muysken, 1986). Under this view, L2 sentence processing is structurally shallow, lacking detailed syntactic representations, such as movement dependencies and referential chains (Felser & Cunnings, 2012; Patterson, Trompelt, & Felser, 2014).

In neurocognitive research, hemodynamic studies (e.g. fMRI) show that late-learned L2s use the same general anatomical regions as L1s, with over -activation of the prefrontal cortex indicating increased effort (see Indefrey, 2006; Abutalebi, 2008, for reviews and Stowe (2006) for criticism). Such over-activation seems to diminish with increased proficiency. At the same time, electroencephalographic (EEG) research highlights potentially significant differences in event-related potential (ERP) responses to grammatical violations. These studies have shown increasing sensitivity to violations as acquisition progresses (Alemán Bañón, Fiorentino, & Gabriele, 2014, Foucart & Frenck-Mestre, 2012; Morgan-Short, Sanz, Steinhauer, & Ullman, 2010; Tanner, Inoue, & Osterhout, 2014). Some argue for native-like attainment, even among adult learners (Bowden, Steinhauer, Sanz, & Ullman, 2013; Sneed, Herschensohn, & Frenck-Mestre, 2015).

A focus on ERP components due to ungrammaticality or infelicity provides a limited view of the neural correlates of grammatical processing; they cannot be linked with any measure of certainty to the epistemological status of mental representations computed in violation detection. Much can be learned from ERP research without reference to ERP components, however (Luck, 2014). Brain activity underpinning grammatical processing can be documented by examining ERPs resulting from grammatical sentences. Specifically, one can examine crucial processing moments presumed to encompass UG-guided computations that are

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not expected in other theoretical paradigms. We focus here on ERP effects that are time-locked to moments at which displaced *wh*-expressions with distinct constituent structures and downstream implications are re-represented in cyclic movement. Effects mirroring theoretical differences in such re-representations would constitute *prima facie* ERP signatures of domain -specificity. The neural correlates of grammatical processing in L1 and L2 can be advanced by examining the neural activity associated with such highly specific computational moments.

We examine EEG waveforms at the embedded-clause complementizer *que* 'that' in interrogative sentences such as *Quelle décision à propos de lui/le concernant est-ce que Paul a dit* ***que*** *Lydie avait rejetée sans hésitation?* 'Which decision about him/regarding him did Paul say that Lydie had rejected without hesitation?' in L1-English/L2-French learners. In French, the alternation *décision à propos de lui/le concernant* 'decision about him/regarding him' is a noun-complement (N-complement) versus a noun-phrase-modifier (NP-modifier) distinction. Although the gendered pronouns *lui* or *le* 'him' share the potential antecedent *Paul*, the grammatical system resolves this relationship in distinct ways for the two structures. The N-complement allows antecedent *Paul* to bind pronoun *lui* under c-command in the course of syntactic derivation. In contrast, the NP-modifier disallows binding because the pronoun is never in the appropriate syntactic configuration in the course of the derivation. Anaphora with NP-modifiers is limited to a discourse-level co-reference construal.

2. Background

When interpreting (1, 2), the masculine pronouns *lui* 'him' in (1) and *le* 'him' in (2) are generally understood as referring to *Paul*.[1]

(1) *Quelle décision à propos de lui est-ce que Paul a dit que Lydie*
which decision at words of him is-it that Paul has said that Lydie
avait rejetée sans hésitation?
had rejected without hesitation
'Which decision about him did Paul say that Lydie had rejected without hesitation?'

(2) *Quelle décision le concernant est-ce que Paul a dit que Lydie avait*
which decision him regarding is-it that Paul has said that Lydie had
rejetée sans hésitation?
rejected without hesitation
'Which decision regarding him did Paul say that Lydie had rejected without hesitation?'

1 However, it is possible these pronouns may receive some other individual (masculine) value determined by the discourse context.

Despite small differences in interpretative possibilities,[2] (2) is typically synonymous with (1). Crucially, however, they differ syntactically: *à propos de* is a PP introduced by the preposition *à; concernant* is a modifying participial clause.[3] Chomsky (1995) follows Lebeaux (1988) in arguing that complements and modifiers engage the computational system differently. As shown in (3), the N-complement—lexically marked with *à* in French—qualifies its head noun *décision* at every step of computation involving the noun. In contrast, the NP-modifier *le concernant* qualifies the noun phrase only after all cycles of computations satisfying lexical requirements have applied to it, as shown in (4).

(3) [<quelle décision à propos de lui> [est-ce que [Paul a dit [< quelle décision à propos de lui > [que Lydie avait rejetée < quelle décision à propos de lui > sans hésitation]]]]]

(4) [<quelle décision> le concernant [est-ce que [Paul a dit [< quelle décision> [que Lydie avait rejetée < quelle décision > sans hésitation]]]]]

In the derivation in (3), a pronoun in an NP-complement can enter into a referential chain with a matching c-commanding expression as relevant binding domains are computed. The embedded clause is the minimal domain containing the pronoun and a subject, and pronouns are free in this domain (Chomsky, 1988). The pronoun *lui* can therefore be bound only by *Paul* at the foot of the chain inside the embedded clause. It is interpreted as a bound variable as soon as it is feasible to do so and linked to the position held by *Paul* at the semantic interface. In contrast, no binding is possible with NP-modifiers, as the pronoun is not in a c-commanded position at any point in the derivation in (4). Thus, *le* and *Paul* do not enter into a syntactic dependency, but rather in discourse co-reference, each expression referring independently to the same value.

Binding involves the computation of a referential chain in an anticipated embedded clause. Thus, as complementizer *que* 'that' induces a new cycle of computations in which each displaced constituent is re-represented, the availability of binding should yield a distinct ERP profile. Indeed, different referential processes are known to yield distinct ERP profiles. Van Berkum, Brown, Hagoort, and Zwitserlood (2003) found negative deflections in the anterior scalp at around 300 ms after the onset of an ambiguous pronoun. Burkhardt (2005) examined syntactic versus discourse-level construal of pronouns, logophors, and new NPs in native speakers (NSs) of English. A range

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[2] With the N-complement structure in (1), the decision directly affects Paul, whereas in (2), with the NP-modifier structure, the decision could indirectly affect Paul.

[3] The expressions *à propos*/*au sujet* 'about' as arguments of nouns allow extractions (i.) whereas *concernant* 'concerning' as a modifier does not.

(i) A propos/au sujet de qui$_i$ Lydie a-t-elle pris une décision *ec*$_i$?
'Who(m) did Lydie make a decision about?'

(ii) *Concernant qui$_i$ Lydie a-t-elle pris une décision *ec*$_i$?
'*Who(m) did Lydie make a decision concerning?'

of effects involving negative deflections induced by logophors or pronouns were reported. Reflexive pronouns that could not be bound in syntax elicited a negativity over anterior sites between 300-450 ms compared to syntactically bound reflexives. In L1 Portuguese, Leitão, Branco, Piñango, and Pires (2009) found that pronouns without c-commanding antecedents (interpreted via discourse co-reference) triggered negative deflections from 250-450 ms in the anterior area and from 400-600 ms in the central-medial region. Hence, syntactically mediated interpretations of pronouns are distinguished from discourse-level interpretations by distinct ERP waveforms at 250-600 ms in NSs.

In the present study, pronouns in the *à propos de lui* N-complement construction are re-represented via cyclic movement as the complementizer *que* 'that' introduces an embedded clause, in contrast with pronouns in the *le concernant* NP-modifier construction. The (possibility of) a matching syntactic antecedent binding the reconstructed pronoun in the N-complement construction (alone) should result in an ERP deflection. Hence, at complementizer *que* 'that', the syntactic computations in (3, 4) predict ERP deflections due to syntactic binding in (3) versus discourse co-reference in (4). Because reconstruction is a basic property of movement (Barss, 2002), ERP profiles due to binding (if found) would constitute domain-specific neural evidence of detailed syntactic structures. If found in nonnative speakers (NNSs), such ERP effects would suggest domain specificity in L2 associated with the computation of intermediate traces in cyclic computations (Dekydtspotter, Donaldson, Edmonds, Liljestrand Fultz, & Petrush, 2008, Dekydtspotter & Miller, 2013; Miller, 2015; Pliatsikas & Marinis, 2013). Dissimilar L1/L2 binding-related ERP deflections would point to the recruitment of distinct neural resources despite similarity at the mental level in which both L1 and L2 processing distinguish the possibility of binding. A lack of binding-related ERP deflection in L2 versus L1 French would indicate failure to discern the distinct structures and would be consistent with, but not definitive proof of, the unavailability of binding (Felser & Cunnings, 2012; Patterson et al., 2014).

3. The study

3.1. Epistemological Hypotheses and ERP Predictions

We hypothesize that in a cyclic *wh*-movement dependency, an intermediate landing site is computed as the edge of the embedded clause is established by the complementizer *que* 'that'. Importantly, with an NP-modifier construction the cycle of computations for the embedded clause cannot support a binding chain. There is thus no further anaphora-related processing in the syntactic module beyond the interface between syntax and discourse-semantic representations.

EEG is suited to address the question of L2 epistemology from a neural perspective because of its high temporal resolution. We argue that ERPs provide a highly specific signature of syntactic versus discourse processes at the complementizer *que* 'that'. Without detailed syntactic computations (i.e. shallow structures), processing at the complementizer should involve a single general process of anaphora in discourse-semantics (Felser & Cunnings, 2012; Patterson et al., 2014). If this is the case, L2 neural activity will naturally not reflect two distinct processes. The neural activity of the brain might, therefore, suggest the domain-specific or general nature of L2 computations.

3.2. Stimuli and methods

Stimuli were 200 items divided in 4 blocks, including 100 critical structures involving 25 quadruples on a 2 x 2 design (Construction: N-complement/NP-modifier * Antecedent: Main clause match/mismatch) as in (5a-d).

(5) a. Quelle décision à propos de lui est-ce que Paul a dit <u>que</u> Lydie avait rejetée sans hésitation?
b. Quelle décision le concernant est-ce que Paul a dit <u>que</u> Lydie avait rejetée sans hésitation?
c. Quelle décision à propos de lui est-ce que Lydie a dit <u>que</u> Paul avait rejetée sans hésitation?
d. Quelle décision le concernant est-ce que Lydie a dit <u>que</u> Paul avait rejetée sans hésitation?
'Which decision **about/regarding him** did Paul/ Lydie say <u>that</u> Lydie/Paul had rejected without hesitation?'

16 advanced L1-English NNSs and 16 NSs of French had previously provided similar interpretive judgments for the two constructions, accepting the construal of the gendered pronouns *lui* and *le* with the matrix-clause subject at similarly high rates in *à propos de lui* and *le concernant* (NNSs: 96%/96%; NSs: 91%/89%). The 100 distractor items involved complex interrogative structures and permutations similar to target items.

We measured EEG waveforms at *que* 'that', when the pronoun can be construed with a matching antecedent with respect to a 'no-gender match' base condition. (5a) is an example of the anaphora condition for N- complements, given that the masculine pronoun *lui* can be anaphoric with *Paul*, whereas (5c) is the base condition because masculine *lui* cannot be construed with *Lydie*. The difference between the EEG waveforms for (5a) and (5c) will therefore reveal the ERP effects that are specifically linked to anaphora under reconstruction with N-complements. Likewise, (5b) represents the anaphora condition for NP-modifiers, given that the masculine pronoun *le* can be co-referential with *Paul*. In contrast, (5d) provides the base condition because masculine *le* cannot be co-referential with *Lydie*. The difference between the EEG waveforms for (5b) and (5d) will likewise provide the ERP effects specifically linked to anaphora with NP-modifiers.

Stimuli were presented visually in four blocks via E-prime (PST, Inc); stimuli were randomized within each block and blocks were presented in random order. The interrogative sentences appeared word by word, each word appearing for 300 ms followed by a 250-ms blank slide. This pace was based on reading speed measured for NNS and NS participants on a self-paced reading task with related stimuli, and was also piloted to confirm that it was appropriate for both participant groups. Respondents were trained to read interrogatives and then accept or reject follow-up comprehension statements. In the training items, all interrogatives were followed by a comprehension statement; in the task, only one half were. This maintained participant attention without being too taxing. Naturally, a set of interrogatives seems plausible in only a limited set of situations. Thus, respondents were introduced to a context involving two characters who are devoted followers of a TV series. One of the characters, however, had missed out on some episodes and asked the other character questions to fill in the missing information.

3.3. Participants and testing procedures

We report results from 15 right-handed NSs of French and 16 right-handed L1-English L2-French NNSs. Participants first reviewed experimental procedures and reaffirmed consent. After providing biographical information, they completed a C-test consisting of 50 partially missing words (25 content words and 25 function words). This test was divided in two paragraph-length texts with a time limit of 5 minutes for each paragraph (Renaud, 2010). Finally, participants completed the EEG experiment, with each of the four blocks lasting 13 minutes; including breaks, the total task time was around one hour. This ensured that the subjects would not be fatigued, and could be expected to stay engaged.

NNSs were adult learners of French (average age=33) who began acquiring French during secondary schooling or later. These participants were graduate students in the US at the time of testing but had spent some time abroad, with an average total length of stay of 1.4 years. C-test scores (average 47.5/50; range 41-50) clearly indicated that they were well above intermediate-level learners, who typically average around 25 points for low intermediates (second semester) and 30 points for high intermediate learners (fourth semester). Our NSs of French (average age=30) were also tested in the US, where most were graduate students, participating in exchange programs, or visitors to campus. They had on average lived abroad 2.3 years at the time of testing. The average C-test score was 49.5/50, with a range from 45-50.

3.4. EEG procedures

EEG was recorded continuously at 1000 samples per second via a 64-electrode EGI system and then divided into 5-second epochs starting with *est-ce que* and running to the end of the interrogative. Impedances were kept below 50 kΩ, and were checked between each block. The EEG signal was collected using a Net Amps 300 amplifier. All preprocessing and data cleaning procedures were performed using the eeglab toolbox (Delarme & Makeig, 2004). Data were filtered offline with a .1-100-Hertz band-pass filter. Line noise was removed using the CleanLine plugin for eeglab (Mullen, 2012). Then, in accordance with a protocol for epoch and channel rejections that included two Independent

Component Analyses, data were cleaned of artefacts, such as blinks, ocular movements, and EMG. 87% of NS and 86% of NNS trials were retained. Both groups were accurate on comprehension questions (NSs, 88%; NNSs, 91%), so all remaining trials were included in the analysis. Analysis was performed on ERPs referenced to average mastoids. ERP waveforms were baseline-corrected with respect to the 200 ms in the blank slide immediately prior to the onset of our region of interest, the complementizer *que* 'that'.

3.5. Analysis

A mixed linear model with random effects for subjects was used to investigate ERPs at complementizer *que* 'that'. We address central questions about the neural underpinnings of grammatical computations in L2 sentence processing in stepwise fashion. We first consider the degree to which NSs and NNSs might produce binding-related ERP effects suggestive of implicit computations as complementizer *que* 'that' is encountered. These are determined by the presence of a Construction (N-complement/NP-modifier) * Antecedent (Main clause match/mismatch) interaction in a 100-ms measurement window found exclusively within the time period of 300 ms to 700 ms after the onset of complementizer *que* 'that'. The effect must not be statistically significant before 300 ms, as a continuous effect would not uniquely point to binding in cyclic movement. [4] Our approach, therefore, focuses first on the presence of a statistical ERP effect at the clause edge due to binding under reconstruction and then, if such an effect is present, on the degree to which NS and NNS patterns echo one another.

ERP signatures of binding under reconstruction should distinguish between N-complement and NP -modifier structures and reflect the presence of a matching antecedent yielding an interaction. Such ERP signatures address the fundamental nature of mental representations in L1 and L2. Second, our analysis addresses the characteristics of such ERPs in L1 versus L2, focusing on the latency, amplitude, and localization of L2 ERPs in contrast with L1 counterparts.

4. Results

For the NSs of French, the mixed linear analysis, performed for each 100-ms increment, showed significant interactions, with all $Fs(1,42) > 5$ and ps $< .05$, in the 450 -700 ms period on electrodes E26, E27, E28/P3 (Figure 1a-c) in the left parietal region above the ear (Figure 1d). The interaction is strongest between 550-650 ms, with Fs$(1,42) > 8$ with ps $< .01$. As Figures 1a-c make manifest, this effect is due to negative deflections induced by N-complements with early antecedent matches for the pronouns, allowing for binding under reconstruction. These binding-related ERP effects arose in the absence of significant interactions

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4 This protects against the possibility that the actual effect would occur before *que* 'that' and would already have been present in the baseline.

before 300 ms. These interactions are, therefore, not the product of a continuous effect, but rather arise as a clause-edge effect. An ERP effect of anaphora with a negative deflection at 400-600 ms in the central parietal region at P3 was also reported by Burkhardt (2005) for logophors vis-à-vis proper names.

The NNSs of French showed a statistically significant interaction at electrode E56 in the right-anterior scalp, $F(1,45) = 4.783$, $p = .03$, between 550-650 ms (Figure 2). As Figure 2 reveals, this interaction is the result of a positive deflection induced by N-complements with early antecedent matches for the pronouns (5a), allowing for the possibility of binding under reconstruction. This binding-related ERP effect also arose in the absence of significant interactions before 300 ms. This interaction also, therefore, seems not to be the product of a continuous effect, but rather arises as a possible clause-edge effect in L2 sentence processing.

Figure 1. Grand mean ERP waveforms in left parietal region for (5a-d): N-complement, early match (5a, dashed dark line); NP-modifier, early match (5b, solid dark line); N-complement, late match (5c, dashed light line); NP-modifier, late match (5d, solid light line). Time = 0 is onset of critical word *que* 'that.'

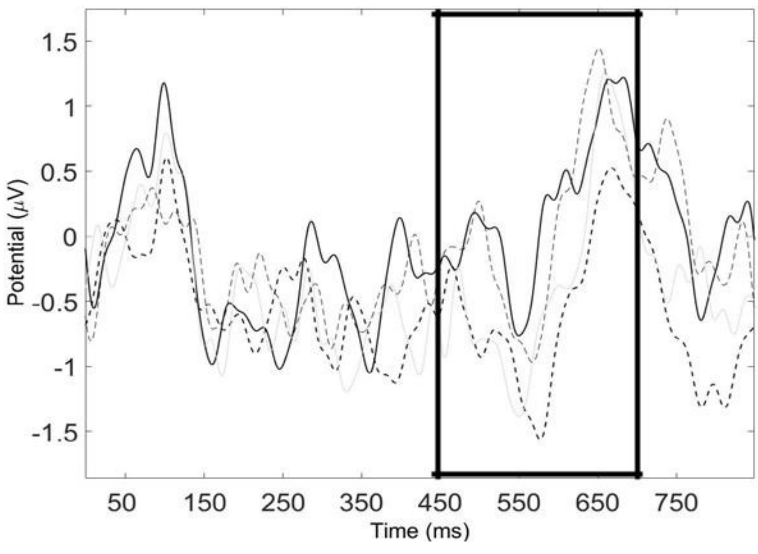

Figure 1a. NSs, E26

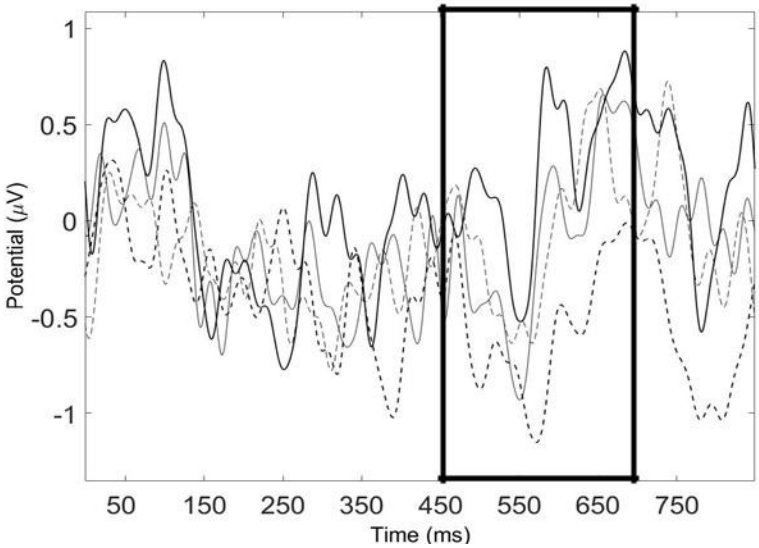

Figure 1b. NSs, E27

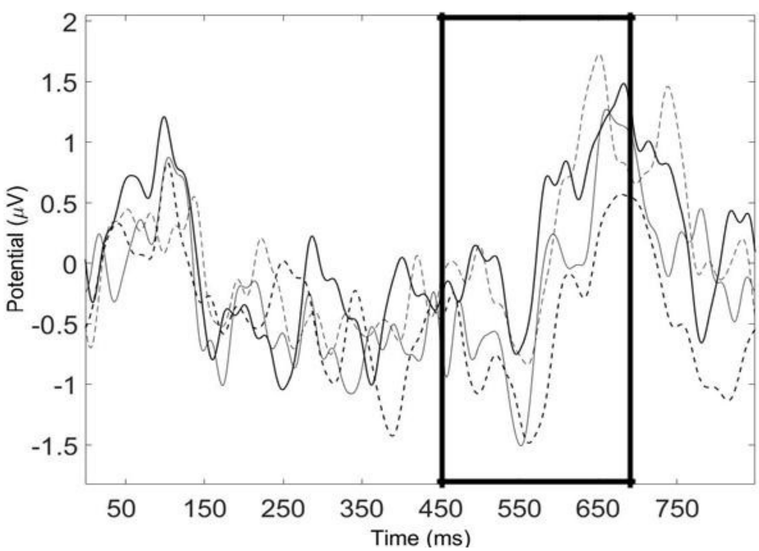

Figure 1c. NSs, E28

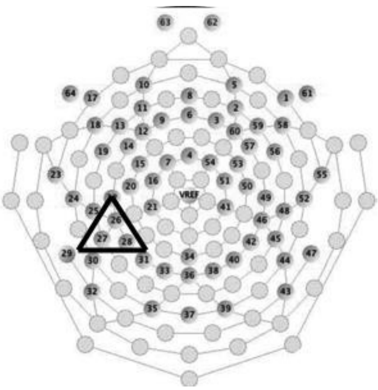

Figure 1d. Location of electrodes on scalp

Figure 2. Grand mean ERP waveforms for (5a-d): N-complement, early match (5a, dashed dark line); NP-modifier, early match (5b, solid dark line); N-complement, late match (5c, dashed light line); NP-modifier, late match (5d, solid light line). Time = 0 is onset of critical word *que* 'that.'

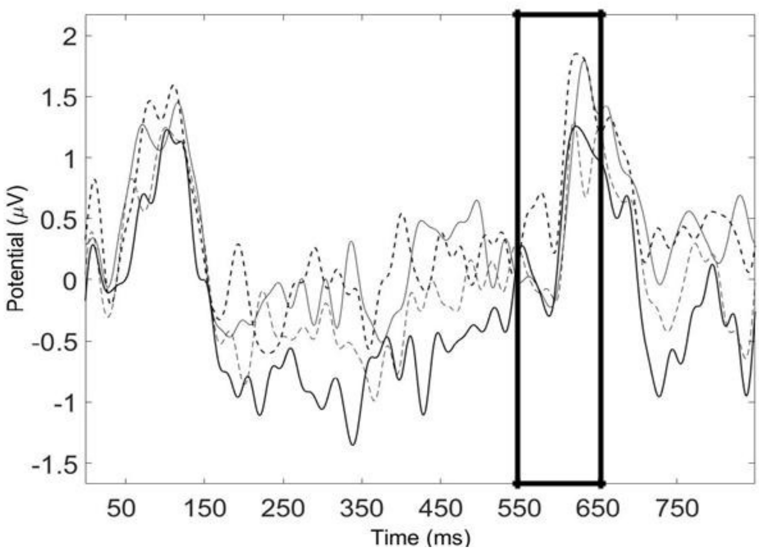

Figure 2a. NNSs, E56

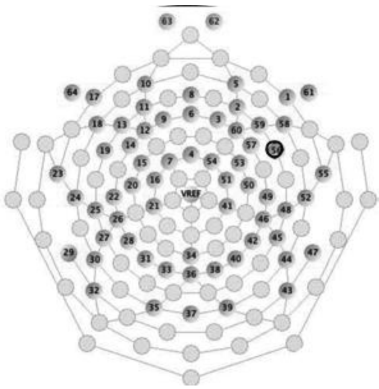

Figure 2b. Location of electrode on

scalp **5. Discussion**

These contours of the ERP data offer new evidence concerning the domain-specificity of computations in L1 and (possibly) L2 sentence processing. ERPs distinguishing the possibility of binding seem confirmatory of the claims of standard generative theory that the anaphoric processes involved in the interpretation of N-complements versus NP-modifiers differ. Across the NS and NNS groups, the condition inducing syntactic binding—where *wh*-movement requires a re-representation that includes the noun complement—resulted in a marked deflection of ERP waveforms around 500 ms after the onset of the complementizer, in contrast to the other three conditions. This constitutes *prima facie* evidence that the mental representations of NSs and NNSs alike distinguish between N-complements and NP-modifiers, and crucially involve distinct processes of anaphora resolution as a result. Such distinctions in ERP profiles seem to threaten shallow processing hypotheses, according to which only a single process (i.e. discourse co-reference) should be involved in real time.

Although NNSs might compute highly domain-specific mental representations, their neural manifestations are not native-like ERPs (cf. Bowden et al., 2013; Sneed et al., 2015). The ERP profiles of NSs and NNSs differed in three fundamental ways: First, whereas NSs showed a negative deflection, NNSs showed a positive deflection. Second, whereas NSs showed a left parietal distribution, NNS ERPs showed a right central anterior scalp distribution. Finally, whereas NSs showed a robust effect on multiple nodes, NNS ERPs were significant on a single node. One might argue that the weaker NNS ERP effects could point to shallower structural representations. For our part, however, we find that denying the existence of an ERP effect that reaches statistical significance constitutes far too drastic a move. Rather, the weaker NNS ERP effects still suggest that an incremental interpretation from the same type of mental computations arose at the clause edge, consistent with cyclic movement.

The NNS ERP effects differ massively in scalp location and in orientation of deflection. NNS EEGs were also positively shifted in voltage. Such differences were observed in spite of the fact that fundamental properties of natural language grammars are involved, and that English (the L1 of the NNSs of French) is similar to French in reliance on *wh*-movement. Thus, L2 acquisition researchers would expect L1 -English L2-French grammars to have these properties by virtue of L1 transfer. Hence, if NSs and NNSs share mental representations of French grammar, the neural resources engaged in sustaining these representations differ substantially and significantly. Distinct neural resources seem engaged in the service of L1 versus L2 interpretation and less robust NNS ERP effects, relative to roughly equivalent sample sizes, suggest greater individual neurophysiological variability in NNSs.

In sum, the presence of a binding -related ERP effect in NNSs does not fit a shallow structure view of sentence processing (Felser & Cunnings, 2012; Patterson et al., 2014). Yet, ERPs in advanced NNSs do not show the degree of convergence predicted by Ullman's (2001) declarative-procedural model (Bowden et al., 2013). The neurophysiology of French NSs' and L1-English L2-French NNSs' processing of anaphora under reconstruction in *wh*-movement appears to differ, when their linguistic computations otherwise make the same distinctions with respect to the possibility of syntactic binding in anaphora resolution.

6. Perspectives

Recent research on ERP components in NNSs reveals individual differences qualified by the eventual appearance of ERP components due to ungrammaticality. Similar scalp ERPs might be a signature of a deep component due to a specific neural substructure. However, the presence or absence of a component does not allow for robust claims about fundamental computational differences. Electrical activity from one set of neurons may be cancelled by electricity from another, so that deep ERP components may not be detected at the scalp. A specific scalp ERP may be generated in multiple ways.

L2 ERP research might proceed independently of component identification, but in a manner that commits to the epistemological status of representations. The evidence we have obtained to date suggests that claims of native-like processing in advanced NNSs (Bowden et al., 2013; Sneed et al, 2015), made on the basis of the identification of ERP components linked to ungrammaticality, seem premature. In addition, our evidence suggests that ERP differences in timing, amplitude deflection, and localization cannot be equated with distinct mental processes between NSs and NNSs: Indeed, the computation of domain-specific mental representations may be accompanied by distinct neural activity.

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